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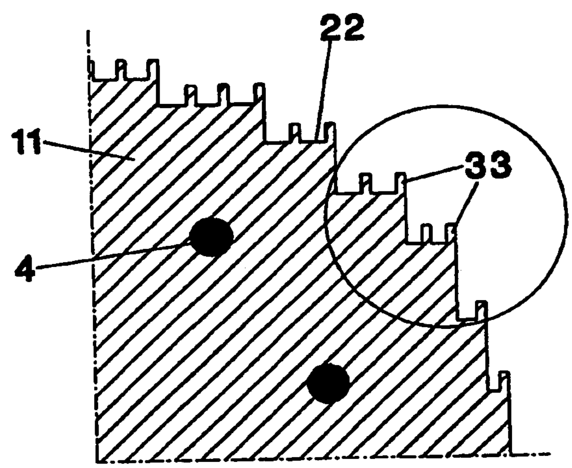
(54) Title: TRANSFORMER CORE WITH COOLING FLANGES

(57) Abstract

A transformer/reactor and a method of manufacturing a transformer/reactor comprising a laminated core (1, 11, 111) and at least one winding for high voltage, each winding comprising a high–voltage cable (6) with means for enclosing an electric field, which high–voltage cable (6) is magnetically permeable and the core (11, 111) being provided with cooling flanges (33, 133).



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TRANSFORMER CORE WITH COOLING FLANGES

The present invention relates to a transformer/ reactor comprising a core and at least one winding, the core being provided with cooling flanges to increase air cooling of the core.

There are transformers/reactors available within all power ranges, from a few W up to about 1000 MW. By power transformers/reactors is usually meant transformers/reactors having a rated power of some hundred kW up to more than 1000 MW, and having a rated voltage of 3 - 4 kV up to very high transmission voltages.

A conventional power transformer comprises a transformer core, hereinafter called core, of laminated oriented sheet metal, usually of ferrosilicon. The core consists of a number of core legs connected to a yoke. Around the core legs there are a number of windings usually called primary, secondary, and regulating winding. In the case of power transformers, these windings are almost always concentrically arranged and spaced along the core legs. The transformer core has a rectangular so called window through which the windings extend. The rectangular window is primarily a result of the production technique used in laminating the core.

Most of the conventional power transformers are usually oil filled. The oil acts as a cooling medium to dispose of the inevitable own losses in the form of heat as well as an insulation means to prevent flashover between different parts of the transformer, e.g. between the windings and the core. Oil filled transformers have many disadvantages which are well known. Among others they are large-sized, unwieldy and heavy, resulting especially in great transport problems, and the requirements as to safety and peripheral equipment are considerable.

It has, however, proved possible to largely replace, especially in the lower part of the above-mentioned power range, oil filled transformers by dry transformers where a solid insulation, usually an epoxy resin, replaces the oil as an insulation means. A transformer of this type is usually air cooled.

As regards reactors, they comprise a core which is provided with only one winding. In other respects, what is stated above about transform rs is largely rele-

vant also in th case of reactors. In particular, it should b noted that also large-sized reactors are oil cooled.

Providing a core of an air cooled or partly air cooled conventional transformer/reactor with cooling flanges presents great difficulties since the jaggedness of the flanges would then lead to increased electric field strength locally and, as a consequence, partial discharges and electric breakdown of the insulation medium.

It is an object of the present invention to provide a transformer, alternatively a reactor, making it possible to eliminate some of the disadvantages associated with the described, traditionally designed power transformers/reactors, and also to provide a method of manufacturing such a transformer/reactor.

A further object of the invention is to increase the cooling effect of transformer cores by providing them with cooling flanges especially in conjunction with transformer/reactor cores presenting at least one winding for high voltage.

The said objects are achieved by a transformer/ reactor of the kind stated in the preamble of claim 1, which presents the feature defined in the characterizing portion of said claim, and by a method of manufacturing thereof according to the preambles of claims 17 and 18 and having the features stated in the characterizing portions of said claims.

Since the winding of the transformer/reactor comprises a high-voltage cable with means for enclosing the electric field, the core can be formed without taking said electric field into consideration and can be provided with cooling flanges without above-mentioned problems.

Additional distinguishing features and advantages will appear from the dependent claims.

As a further distinguishing feature is stated that the high-voltage cable is of a kind comprising a conductor having a number of strands, an inner semi-conducting layer surrounding the conductor, an insulating layer surrounding the inner semi-conducting layer, and an outer semi-conducting layer surrounding the insulating layer. By semi-conducting is meant, in this connection, that the conductivity of the two semi-conducting layers is sufficiently high to essentially equalize the potential al ng the resp ctive lay r, while the conductivity, specially in the outer layer, is low nough not to caus any significant loss s du to induced cur-

rents in the lay r. Th inn r and outer s mi-conducting layers preferably hav a resistivity within the range of 1 - 10^5 ohmcentimetres. The insulating layer preferably has a resistivity of more than 10^5 ohmcentimetres. Each of the two semi-conducting layers thus essentially constitutes an equipotential surface, and the winding with these layers will essentially enclose the electric field. However, one or more additional semi-conducting layers may, of course, be arranged in the insulating layer. Finally, it is said that the high-voltage cable preferably has a diameter within the range of 20 - 250 mm and a conductor area within the range of 80 - 3000 mm^2.

In the device according to the invention the windings are preferably of a kind corresponding to cables with solid extruded insulation currently used for power distribution, e.g. so called XLPE cables or cables with EPR insulation. Such a cable includes an inner conductor comprising one or more strands, an inner semi-conducting layer surrounding the conductor, a solid insulating layer surrounding the inner semi-conducting layer, and an outer semi-conducting layer surrounding the insulating layer. Such cables are flexible which is an essential characteristic in this connection since the technique for the device according to the invention is primarily based on a winding system in which the winding is formed with conductors which are wound into a cylindrical coil. The flexibility of an XLPE cable typically corresponds to a bending radius of around 20 cm for a cable having a diameter of 30 mm, and to a bending radius of 65 cm for an 80 mm diameter cable. In the present application, the term flexible thus refers to the winding being flexible down to a bending radius in the order of 8 - 25 times the cable diameter.

The winding should be made in such a way as to keep its characteristics also during bending and when, in use, being subject to thermal stress. In this respect, it is of great importance that the layers should continue adhering to each other. Here, the material properties of the layers are crucial, above all their elasticity and their relative thermal expansion coefficients. For a cable such as an XLPE cable the insulating layer consists of cross-linked low density polyethylene, and the semi-conducting layers of polyethylene with added carbon black and metal particles. Changes in volum as a result of temperature variations are absorbed entirely as radius variations in th cabl , and owing to the comparatively

small difference between the thermal expansion coefficients of the layers relativ to the elasticity of these materials, radial expansion of the cable will be able to take place without the layers separating from each other.

For example, the insulating layer may comprise a solid thermoplastic material such as low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl-pentene (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene-propylene rubber (EPR) or silicone rubber.

The inner and outer semi-conducting layers may have the same basic material with admixed particles of conductive materials such as carbon black or metal powder.

The mechanical properties of said materials, above all their thermal expansion coefficients, are affected fairly little by the admixture or non-admixture of carbon black or metal powder. The insulating layer and the semi-conducting layers thus essentially have the same thermal expansion coefficients.

For the semi-conducting layers, suitable polymers may also be ethylene vinyl acetate copolymer/nitrile rubber, butyl graft-polyethylene, ethylene acrylate copolymer, and ethylene-ethyl-acrylate copolymer.

Even when different kinds of material are used as a base of the respective layers it is desirable for their thermal expansion coefficient to be of the same magnitude. This applies to the combination of the materials stated above.

The elasticity of the above-mentioned materials is sufficient for possible minor deviations of the thermal expansion coefficients of the materials of the layers to be absorbed in the radial direction of the elasticity so that cracks or other damage will not occur and so that the layers do not separate from each other.

According to an advantageous distinguishing feature, the core contains internal passages which are used to transport a cooling medium as a complement to the core being provided with cooling flanges. Further, cooling of the core and the windings may be achieved by inserting tubes in the passages of the core in which tubes the cooling medium flows. Also other types of cooling of the core and th windings are possible, for instance, arranging cooling tub s adjacent to the

windings as a compl m nt to the cooling flanges of the core. Furth r, the cooling medium in the passages and the tubes may be liquid or gas, e.g. water or helium.

The invention will now be further described using numerals with reference to the accompanying drawings, in which

Fig. 1 shows a sectional view of a quadrant of a conventional transformer/reactor core,

Fig. 2 shows a view, on an enlarged scale, of the part of the section marked by a circle in Fig. 1,

Fig. 3 shows a sectional view of a quadrant of a transformer/reactor core according to a first embodiment of the invention,

Fig. 4 shows a view, on an enlarged scale, of the part of the section marked by a circle in Fig. 3,

Fig. 5 shows a sectional view of a quadrant of a transformer/reactor core according to a second embodiment of the invention,

Fig. 6 shows a view, on an enlarged scale, of the part of the section marked by a circle in Fig. 5, and

Fig. 7 shows a sectional view of a high-voltage cable for a winding of a transformer/reactor according to the present invention.

In Fig. 1 there is shown schematically a principal sketch of a conventional transformer core 1. Here, we see a section through a quadrant of the transformer 1, which could just as well be a reactor core. Small transformer cores are usually put together out of die formed sheet metal sections while larger transformer cores are assembled out of straight pieces which are put together with special sheet patterns at the corners. It is desirable for the section through the core 1 to be circular in order to provide good contact for a winding disposed around the core and to minimize the magnetizing current losses. This implies that a section through the periphery of the actual core forms a stepped surface 2 since the core 1 is composed of a number of plates 3, see Fig. 2, which are superposed in a sheet pattern. Usually, the plates are glued together. By superposing plates, a so called laminated core is provided. Various laminating methods may be used, such as

crossing in several different ways. Thus, in Figs. 1 - 2 a previously known construction and manufacture of a transformer/reactor core 1 is shown.

Figs. 3 and 4 show a first embodiment of the invention in the form of a core 11 with laminate portions 14, as seen in section corresponding to Figs. 1 and 2. As is evident from Fig. 4, a number of laminate portions protrude beyond the actual core with stepped surface 22, said portions forming cooling flanges 33 integrated in the core. Further, as may be seen from Fig. 3, the core is provided with axially disposed cooling passages 4 in which cooling medium is arranged to flow.

Figs. 5 and 6 show a second embodiment of the invention. In this embodiment too, the core 111 is provided with cooling flanges 133 which, as may be seen from Fig. 4, are formed as flange elements 135 including the cooling flanges 133 as well as a connection member 134 in the form of a ring which is connected to the periphery of the core by means of a heat conducting adhesive. Alternatively, the ring may be connected as a pressure connection which is shrunk on by heating. Further, it is evident from Fig. 5 that the core according to this embodiment is provided with axially disposed cooling passages 4 in which cooling medium is arranged to flow. Thus, the cooling flanges 133 are composed of parts mounted on the core 111.

In Fig. 7 there is depicted a cross section through a high-voltage cable 6 which is particularly suited to be used as a transformer winding according to the present invention. The high-voltage cable 6 includes a number of strands 7 with circular cross section of, for instance, copper (Cu). Said strands 7 are arranged in the centre of the high-voltage cable 6. Around the strands 7 there is arranged a first semi-conducting layer 8. Around said first semi-conducting layer 8 there is disposed an insulating layer 9, e.g. an XLPE insulation. Again, around the insulating layer 9 there is disposed a second semi-conducting layer 10. The illustrated cable differs from a conventional high-voltage cable in that the outer mechanical sheath and the metal screen normally surrounding such cable have been eliminated. The concept high-voltage cable in the present application thus does not necessarily include the metal screen and the sheath normally surrounding such cable for power distribution. The high-voltage cable has a diameter within th rang of 20 - 250 mm and a conductor area within the range of 80 - 3000 mm^2.

Th insulated conductor or high-voltage cabl 6 is fl xible so that it may be bent to form windings, having been straight at the time of manufacture. Further, the various layers 8, 9, 10 of the high-voltage cable are intended to adhere to each other also when the insulated conductor or high-voltage cable 6 is being bent. In addition, at least two of said adjacent layers 8, 9, 10 of the machine winding have essentially equally high thermal expansion coefficients.

In both embodiments, each winding of the transformer/reactor includes a high-voltage cable 6 having means for enclosing an electric field, which high-voltage cable is also magnetically permeable. Further, the plates 3 of the transformer/reactor are made of magnetically oriented steel or of amorphous steel. Moreover, the transformer/reactor is of the dry transformer/dry reactor type, i.e. it is not cooled with oil. Finally, it should be mentioned that the invention, of course, is also applicable to a multiphase transformer/reactor by combining, for instance, three cores formed according to the invention.

CLAIMS

1. A transformer/reactor comprising a laminated core (1, 11, 111) and at least one winding for high voltage, **characterized** in that each winding includes a high-voltage cable (6) having means to enclose an electric field, which high-voltage cable (6) is magnetically permeable, and that the core (11, 111) is provided with cooling flanges (33, 133).

2. A transformer/reactor according to claim 1, **characterized** in that the core (11, 111) includes a number of laminate portions (14) protruding beyond the actual core and thus forming cooling flanges (33) integrated in the core.

3. A transformer/reactor according to claim 1, **characterized** in that the cooling flanges (133) are comprised of parts mounted on the core (111).

4. A transformer/reactor according to any of claims 1 - 3, **characterized** in that the winding is flexible and includes an electrically conductive core surrounded by an inner semi-conducting layer (8), an insulating layer (9) of solid material surrounding the inner semi-conducting layer (8), and an outer semi-conducting layer (10) surrounding the insulating layer (9), which layers (8, 9, 10) abut against each other.

5. A transformer/reactor according to any of claims 2 - 4, **characterized** in that the high-voltage cable (6) is of a kind including a conductor with a plurality of strands (7), an inner semi-conducting layer (8) surrounding the conductor, an insulating layer (9) surrounding the inner semi-conducting layer, and an outer semi-conducting layer (10) surrounding the insulating layer.

6. A transformer/reactor according to claim 5, **characterized** in that the high-voltage cabel (6) has a diameter within the range of 20 - 250 mm and a conductor area within the rang of 80 - 3000 mm^2.

7. A transformer/reactor according to any of claims 1 - 6, **characterized** in that the plates (3) are made of magnetically oriented steel.

8. A transformer/reactor according to any of claims 1 - 7, **characterized** in that the plates (3) are made of amorphous steel.

9. A transformer/reactor according to any of the preceding claims, **characterized** in that the laminated core contains internal passages (4) for a cooling medium.

10. A transformer/reactor according to any of the preceding claims, **characterized** in that the insulated conductor or high-voltage cable (6) is flexible.

11. A transformer/reactor according to claim 10, **characterized** in that the layers (8, 9, 10) are arranged to adhere to each other also during bending of the insulated conductor or high-voltage cable.

12. A transformer/reactor according to any of the preceding claims, **characterized** in that at least two adjacent layers (8, 9, 10) of the machine winding have essentially equally high thermal expansion coefficients.

13. A transformer/reactor according to any of the preceding claims, **characterized** in that the said layers (8, 9, 10) are made of materials having such elasticity and the relation between the thermal expansion coefficients of the materials being such that, in operation, the changes in volume of the layers (8, 9, 10) caused by temperature variations are brought to be absorbed by the elasticity of the materials so that the layers will continue to abut against each other during the temperature variations occurring in operation.

14. A transformer/reactor according to claim 13, **characterized** in that the materials of the said layers (8, 9, 10) present high elasticity.

15. A transformer/reactor according to any of claims 13 - 14, **charact rized** in that the thermal expansion coefficients of the materials of the said layers (8, 9, 10) are substantially equally high.

16. A transformer/reactor according to any of claims 13 - 15, **characterized** in that each of the semi-conducting layers (8, 10) essentially constitutes an equipotential surface.

17. A method of manufacturing a transformer/reactor comprising a core composed of laminate plates and at least one winding, **characterized** in that each winding includes a high-voltage cable (9) with means to enclose an electric field, which high-voltage cable (6) is magnetically permeable and that the laminate plates (14) are laid so that their outer edges define the outer surface (22) of the actual core and so that they protrude beyond the actual core to define cooling flanges (33) integrated in the core.

18. A method of manufacturing a transformer/reactor comprising a core composed of laminate plates and at least one winding, **characterized** in that each winding includes a high-voltage cable (9) with means to enclose an electric field, which high-voltage cable (6) is magnetically permeable and that the laminate plates (14) are laid so that their outer edges define the outer surface (22) of the actual core, after which cooling flanges (133) formed as flange elements (135) with connection means (134) in the form of a ring are connected to the periphery of the core.

19. A method according to any of claims 17 - 18, **characterized** in that the winding is applied after the complete core with cooling flanges has been assembled.

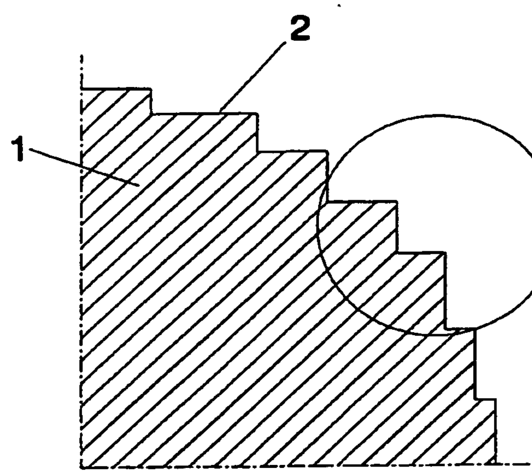

Fig 1

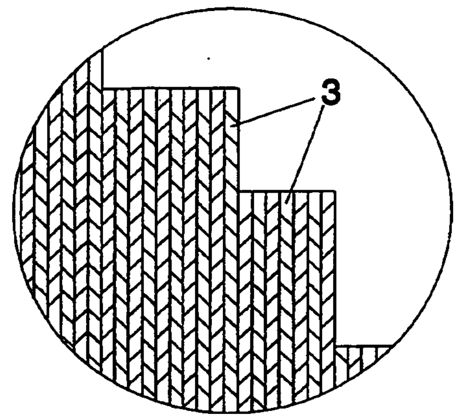

Fig 2

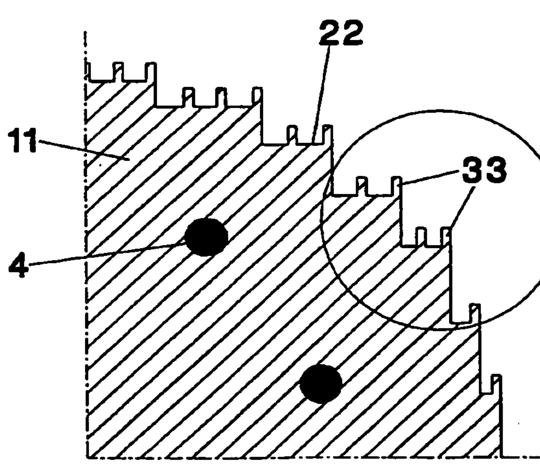

Fig 3

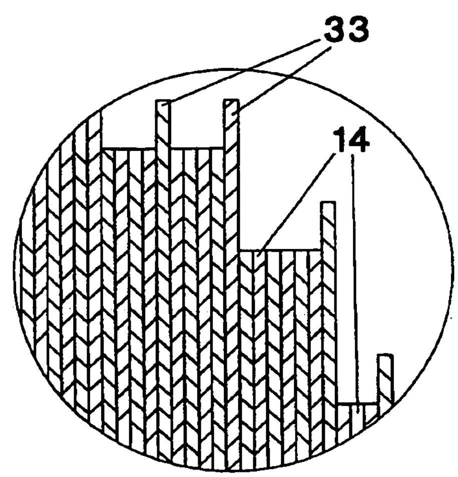

Fig 4

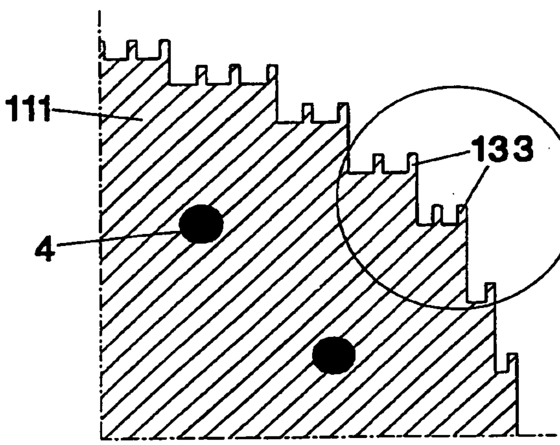

Fig 5

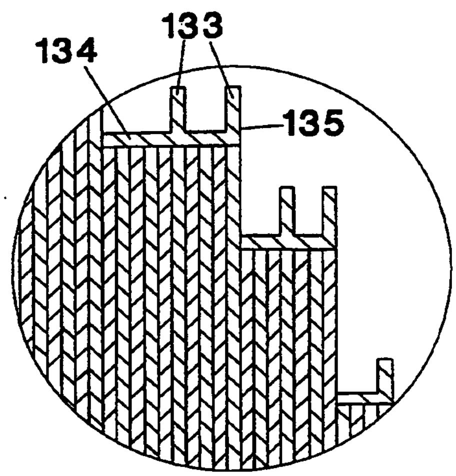

Fig 6

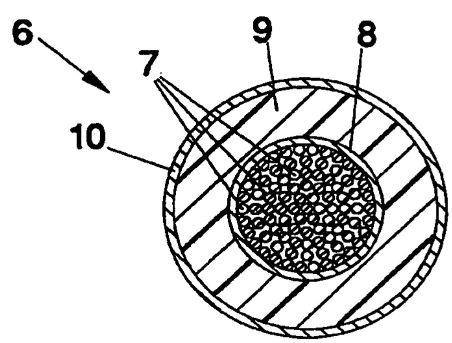

Fig 7